In [1]:
```
import librosa
import os
import numpy as np
import matplotlib.pyplot as plt
import random
import pandas as pd
import IPython.display as ipd
import soundfile
from librosa.util import frame, abs2
```

(1) EDA

(a) Loading the data and finding summary of amplitude and duration of the data

In [2]:
```
data_path = 'data'
```

In [3]:
```
# # remove all clean files
# for class_ in os.listdir(data_path):
#     if class_ == '_background_noise_':
#         continue
#     class_path = os.path.join(data_path, class_)
#     for file in os.listdir(class_path):
#         if file.startswith('clean_'):
#             os.remove(os.path.join(class_path, file))
```

In [4]:
```
def get_amplitude(file_path):
    y, sr = librosa.load(file_path, sr=None)
    return y, sr
```

In [10]:
```
def calc_stats(path):

    statistics = []

    for class_ in os.listdir(path):
        if class_ == '_background_noise_':
            continue
        class_path = os.path.join(path, class_)
        for file in os.listdir(class_path):
            if file.endswith('.wav'):
                file_path = os.path.join(class_path, file)
                y, sr = get_amplitude(file_path)
                duration = librosa.get_duration(y=y, sr=sr)

                stats = {
                    'file': file,
                    'class': class_,
                    'duration': duration,
                    'mean amplitude': np.mean(y),
                    'max amplitude': np.max(y),
                    'min amplitude': np.min(y),
                    'std amplitude': np.std(y),
                }
```

```
                statistics.append(stats)

    return statistics
```

In [11]:
```
df_stats = pd.DataFrame(stats)

print(df_stats)
```

```
                          file     class  duration  mean amplitude  \
0       0165e0e8_nohash_0.wav  backward       1.0       -0.077356
1       017c4098_nohash_0.wav  backward       1.0       -0.000057
2       017c4098_nohash_1.wav  backward       1.0        0.000011
3       017c4098_nohash_2.wav  backward       1.0        0.000014
4       017c4098_nohash_3.wav  backward       1.0        0.000069
...                       ...       ...       ...             ...
105824  ffd2ba2f_nohash_1.wav      zero       1.0        0.000101
105825  ffd2ba2f_nohash_2.wav      zero       1.0        0.000206
105826  ffd2ba2f_nohash_3.wav      zero       1.0        0.000071
105827  ffd2ba2f_nohash_4.wav      zero       1.0        0.000038
105828  fffcabd1_nohash_0.wav      zero       1.0        0.000002

        max amplitude  min amplitude  std amplitude
0            0.714294      -0.948944       0.072488
1            0.840546      -0.809021       0.097710
2            0.658264      -0.565155       0.070762
3            0.799988      -0.753296       0.086518
4            0.820221      -0.647461       0.096033
...               ...            ...            ...
105824       0.217621      -0.321808       0.049302
105825       0.191864      -0.271790       0.050935
105826       0.212341      -0.283813       0.046812
105827       0.171265      -0.197754       0.037636
105828       0.163239      -0.155304       0.025669

[105829 rows x 7 columns]
```

In [13]:
```
df_stats.sort_values(by='class', inplace=True)
df_stats.reset_index(drop=True, inplace=True)
df_stats
```

Out[13]:

	file	class	duration	mean amplitude	max amplitude	min amplitude
0	0165e0e8_nohash_0.wav	backward	1.0	-0.077356	0.714294	-0.948944
1	87070229_nohash_2.wav	backward	1.0	0.000090	0.496307	-0.874329
2	017c4098_nohash_0.wav	backward	1.0	-0.000057	0.840546	-0.809021
3	017c4098_nohash_1.wav	backward	1.0	0.000011	0.658264	-0.565155
4	017c4098_nohash_2.wav	backward	1.0	0.000014	0.799988	-0.753296
...	...	...	...	...	...	...
105824	837a0f64_nohash_3.wav	zero	1.0	0.000087	0.447327	-0.678070
105825	ffd2ba2f_nohash_2.wav	zero	1.0	0.000206	0.191864	-0.271790
105826	ffd2ba2f_nohash_3.wav	zero	1.0	0.000071	0.212341	-0.283813
105827	ff4ed4f3_nohash_0.wav	zero	1.0	0.000052	0.834381	-0.919952
105828	fffcabd1_nohash_0.wav	zero	1.0	0.000002	0.163239	-0.155304

105829 rows × 7 columns

In [15]:

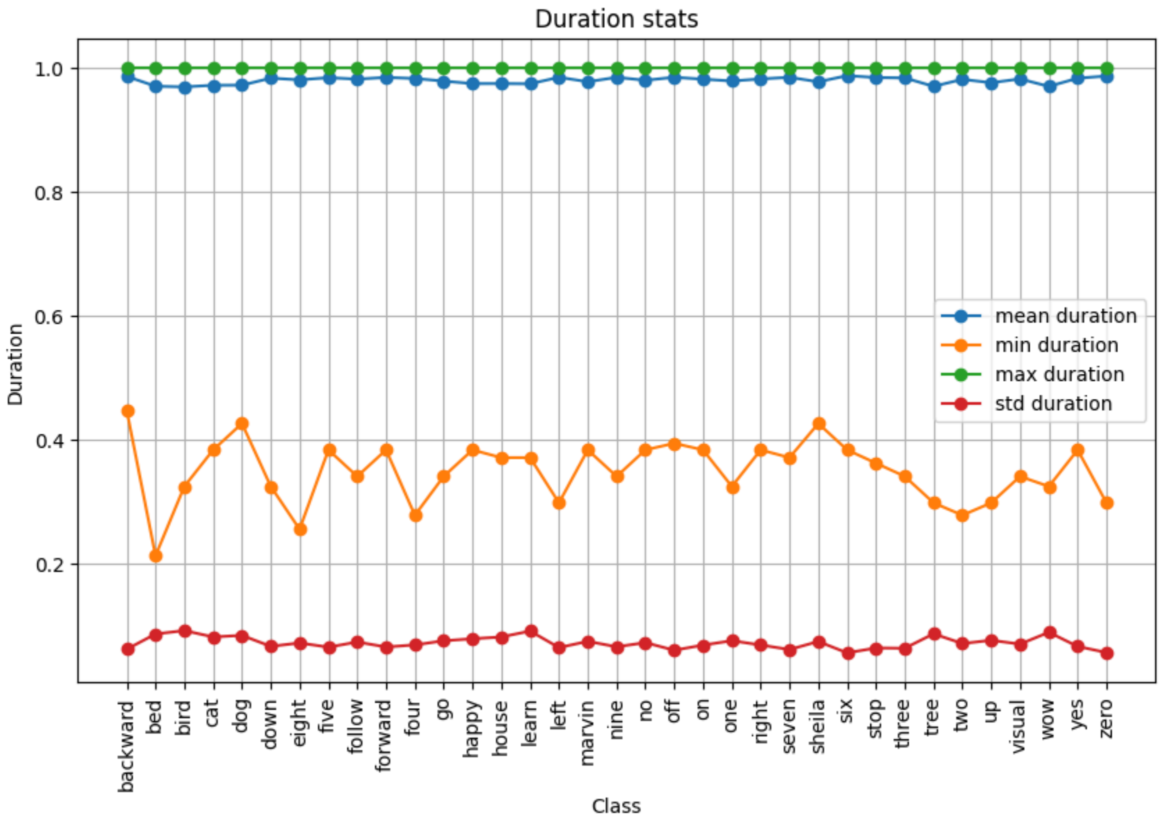
```
amplitude = df_stats.groupby('class').agg({
    'mean amplitude' : ['min', 'max', 'mean', 'std'],
    'max amplitude' : ['min', 'max', 'mean', 'std'],
    'min amplitude' : ['min', 'max', 'mean', 'std'],
    'std amplitude' : ['min', 'max', 'mean', 'std']
})

# print(amplitude)
```

In [16]:

```
duration = df_stats.groupby('class').agg({
    'duration' : ['min', 'max', 'mean', 'std']
})

# print(duration)
```

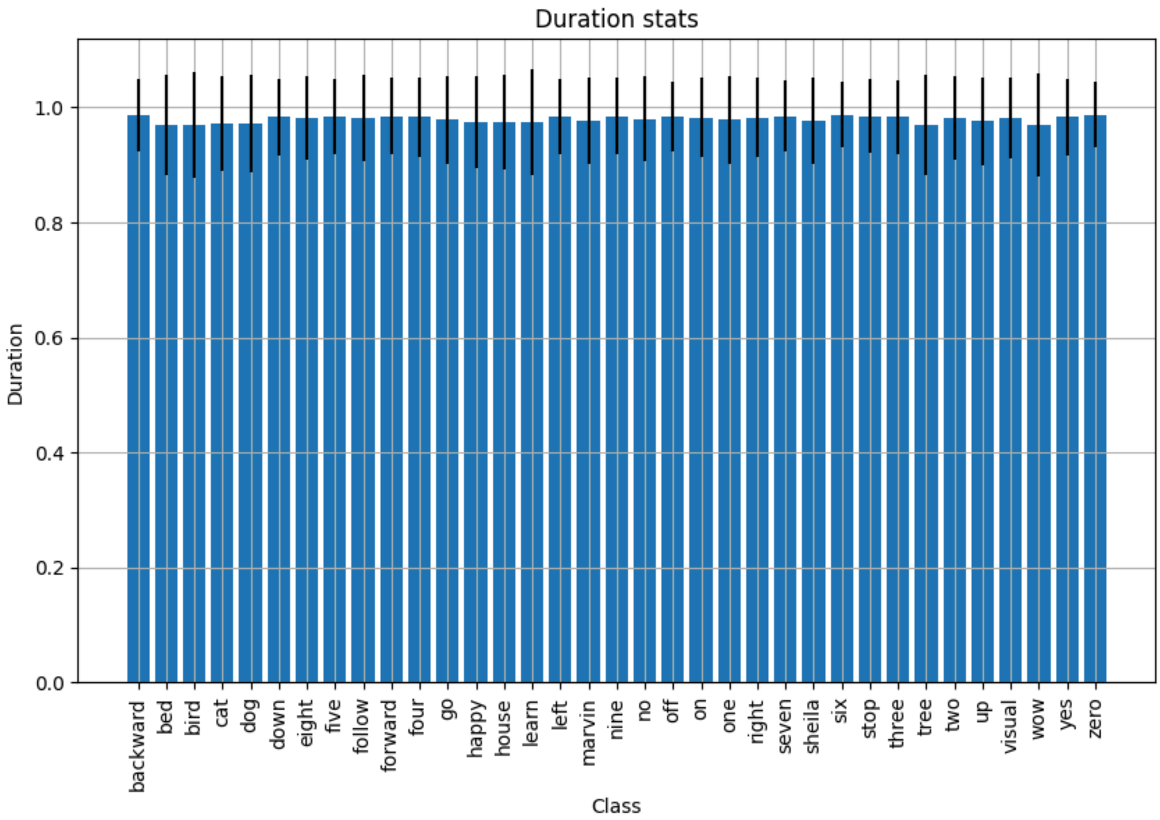
In [17]:

```
# Plotting durations stats
plt.figure(figsize=(10, 6))
plt.plot(duration['duration']['mean'], 'o-', label='mean duration')
plt.plot(duration['duration']['min'], 'o-', label='min duration')
plt.plot(duration['duration']['max'], 'o-', label='max duration')
plt.plot(duration['duration']['std'], 'o-', label='std duration')
plt.title('Duration stats')
plt.xlabel('Class')
plt.ylabel('Duration')

plt.legend()
plt.xticks(rotation=90)
plt.grid()
plt.show()
```



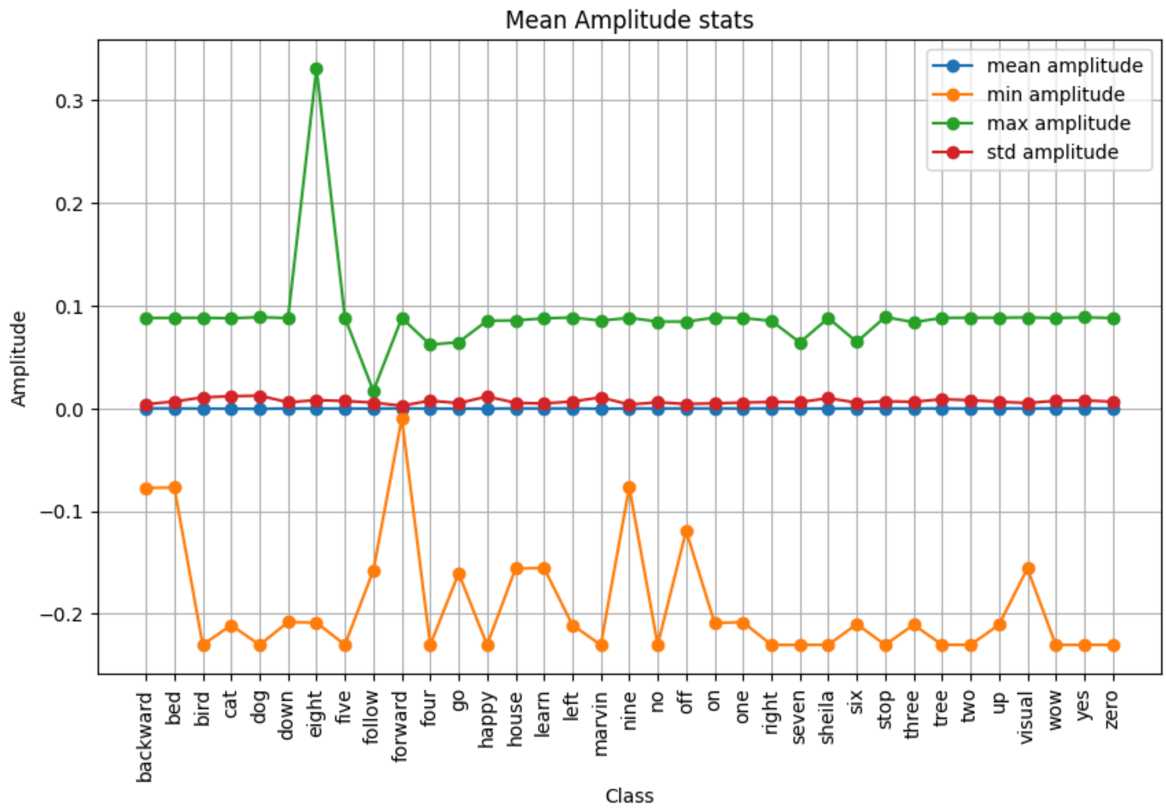
We observe that the mean and max duration are same for all the classes. This is because the data is sampled at 16kHz and the duration is 1 second.

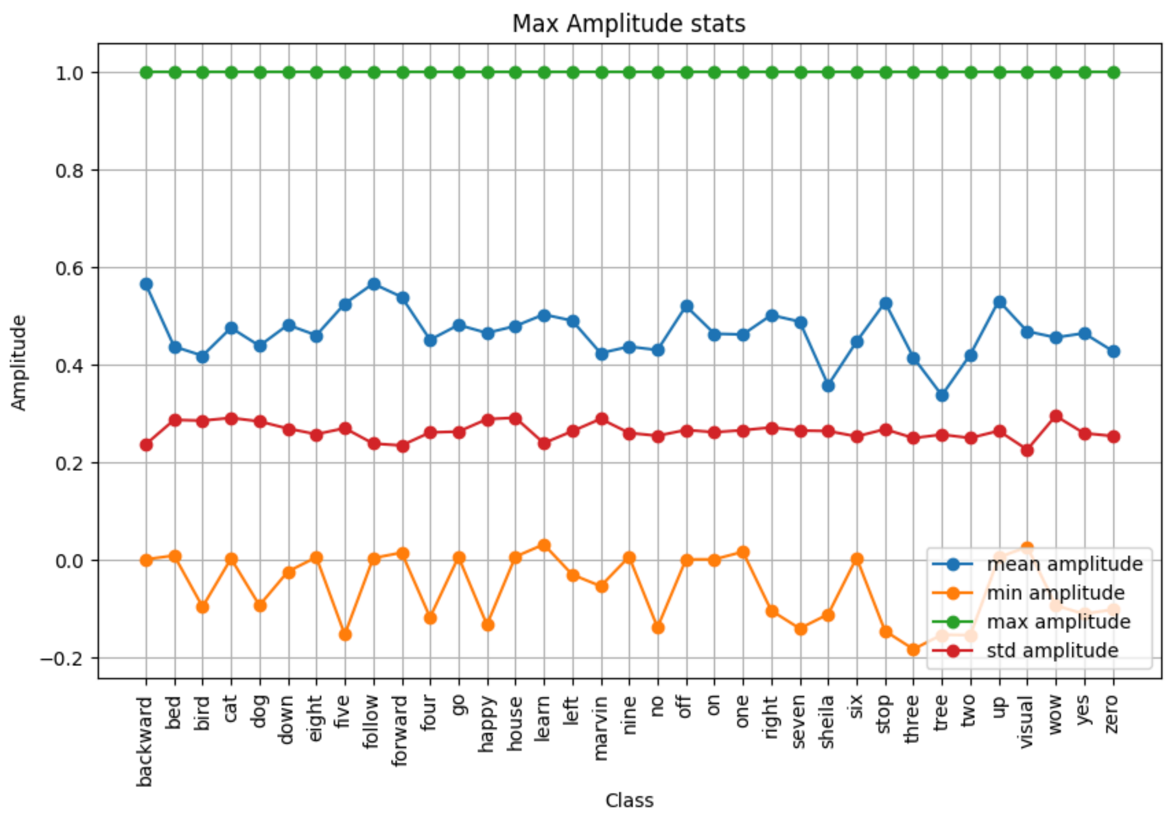
In [18]:
```
plt.figure(figsize=(10, 6))
plt.bar(duration.index, duration['duration']['mean'], yerr=duration['duration'][
plt.title('Duration stats')
plt.xlabel('Class')
plt.ylabel('Duration')
plt.xticks(rotation=90)
plt.grid()
plt.show()
```

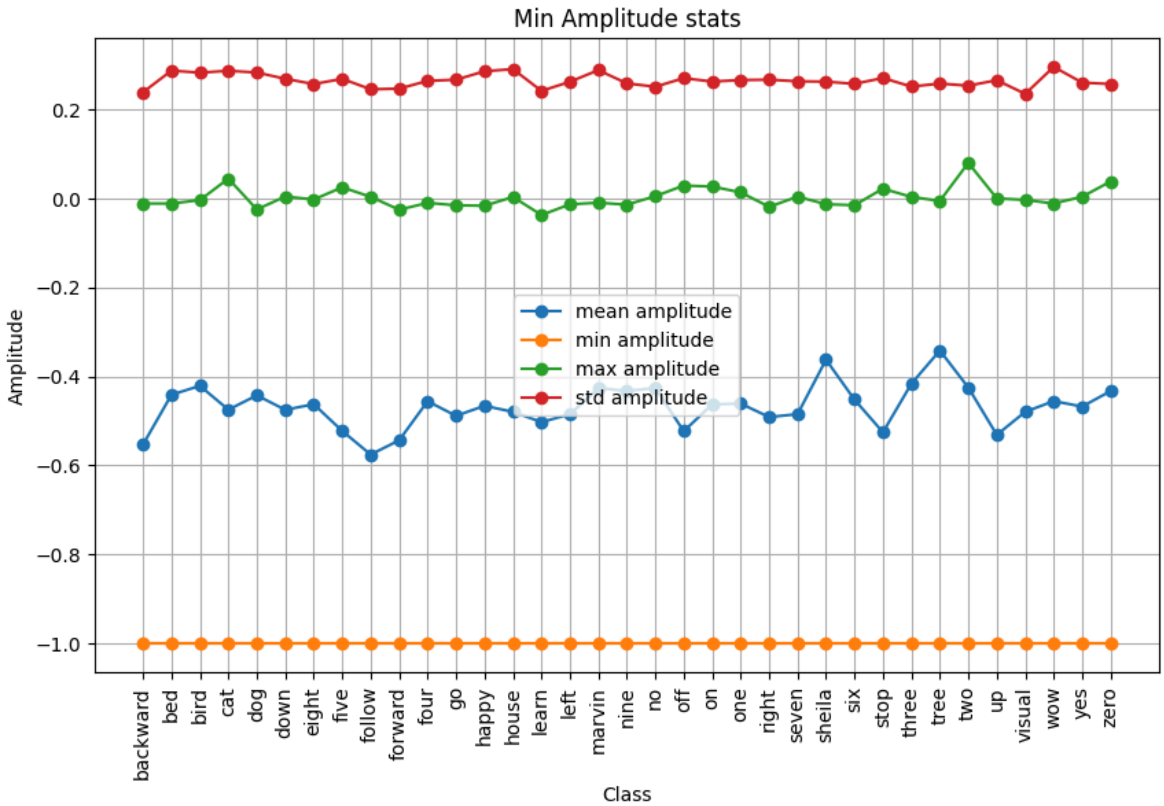


In [19]:
```
# Plotting amplitude stats
plt.figure(figsize=(10, 6))
plt.plot(amplitude['mean amplitude']['mean'], 'o-', label='mean amplitude')
plt.plot(amplitude['mean amplitude']['min'], 'o-', label='min amplitude')
plt.plot(amplitude['mean amplitude']['max'], 'o-', label='max amplitude')
plt.plot(amplitude['mean amplitude']['std'], 'o-', label='std amplitude')
plt.title('Mean Amplitude stats')
plt.xlabel('Class')
plt.ylabel('Amplitude')

plt.legend()
plt.xticks(rotation=90)
plt.grid()

plt.figure(figsize=(10, 6))
plt.plot(amplitude['max amplitude']['mean'], 'o-', label='mean amplitude')
plt.plot(amplitude['max amplitude']['min'], 'o-', label='min amplitude')
plt.plot(amplitude['max amplitude']['max'], 'o-', label='max amplitude')
plt.plot(amplitude['max amplitude']['std'], 'o-', label='std amplitude')
plt.title('Max Amplitude stats')
plt.xlabel('Class')
plt.ylabel('Amplitude')

plt.legend()
plt.xticks(rotation=90)
plt.grid()

plt.figure(figsize=(10, 6))
plt.plot(amplitude['min amplitude']['mean'], 'o-', label='mean amplitude')
plt.plot(amplitude['min amplitude']['min'], 'o-', label='min amplitude')
plt.plot(amplitude['min amplitude']['max'], 'o-', label='max amplitude')
plt.plot(amplitude['min amplitude']['std'], 'o-', label='std amplitude')
plt.title('Min Amplitude stats')
plt.xlabel('Class')
```

```
plt.ylabel('Amplitude')

plt.legend()
plt.xticks(rotation=90)
plt.grid()
plt.show()
```

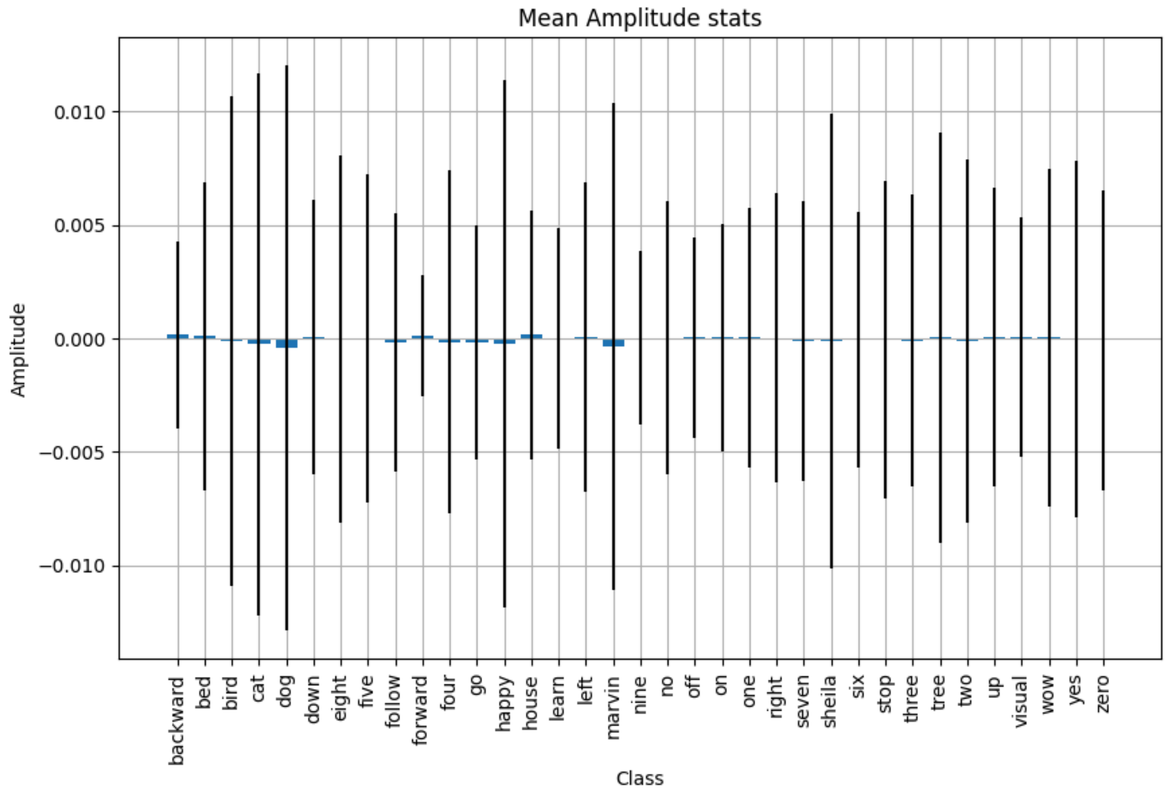


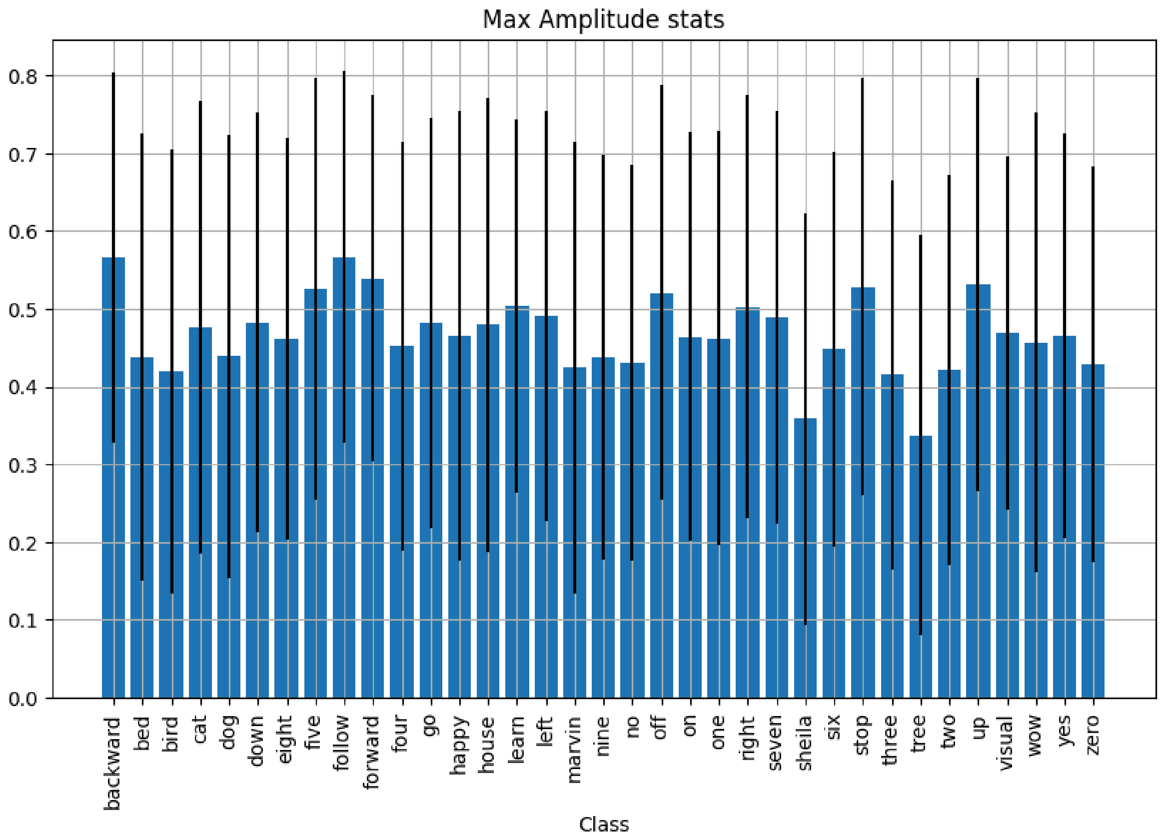


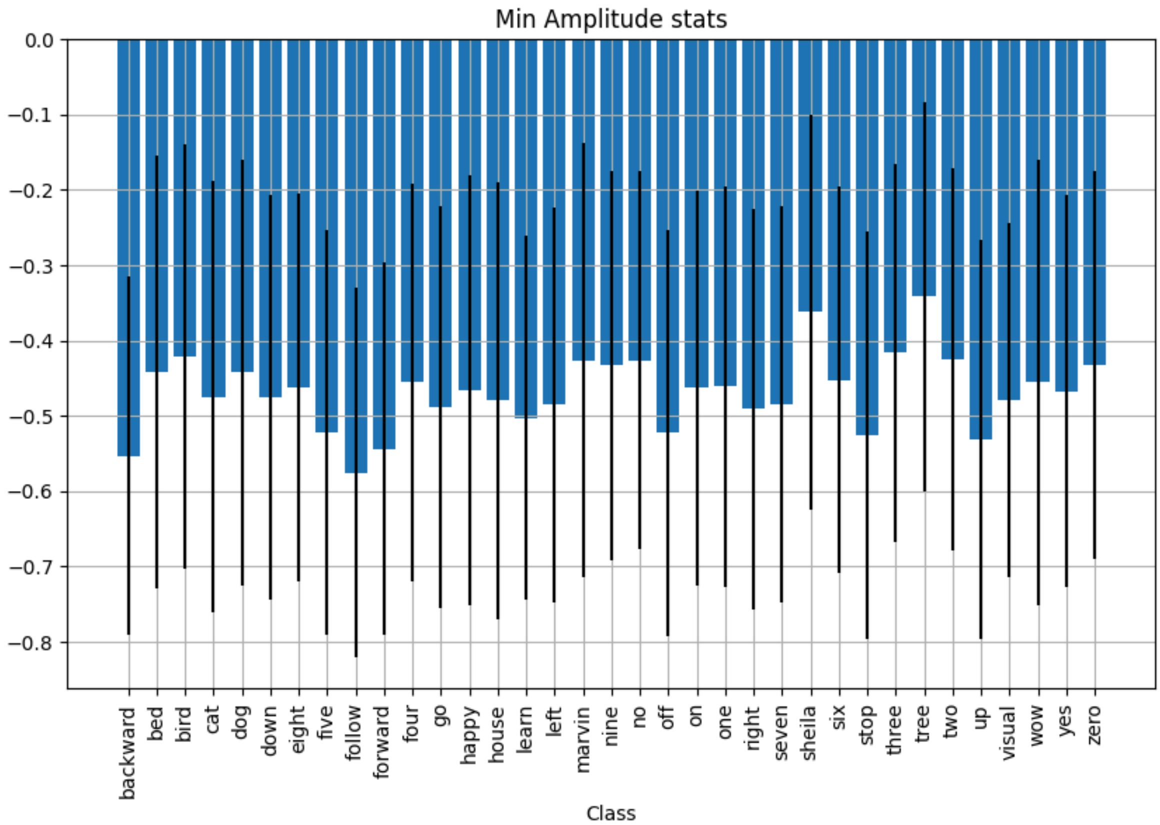


We observe huge veriations in the amplitude of the data. This was bound to happen since some samples might contain noise, some may contain silences and different words might be spoken at different amplitudes.

In [20]:
```
plt.figure(figsize=(10, 6))
plt.bar(amplitude.index, amplitude['mean amplitude']['mean'], yerr=amplitude['me
plt.title('Mean Amplitude stats')
plt.xlabel('Class')
plt.ylabel('Amplitude')

plt.xticks(rotation=90)
plt.grid()

plt.figure(figsize=(10, 6))
plt.bar(amplitude.index, amplitude['max amplitude']['mean'], yerr=amplitude['max
plt.title('Max Amplitude stats')
plt.xlabel('Class')

plt.xticks(rotation=90)
plt.grid()

plt.figure(figsize=(10, 6))
plt.bar(amplitude.index, amplitude['min amplitude']['mean'], yerr=amplitude['min
plt.title('Min Amplitude stats')
plt.xlabel('Class')

plt.xticks(rotation=90)
plt.grid()
plt.show()
```


Mean Amplitude stats
Amplitude
0.010
0.005
0.000
−0.005
−0.010
backward bed bird cat dog down eight five follow forward four go happy house learn left marvin nine no off on one right seven sheila six stop three tree two up visual wow yes zero
Class


Max Amplitude stats
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
backward bed bird cat dog down eight five follow forward four go happy house learn left marvin nine no off on one right seven sheila six stop three tree two up visual wow yes zero
Class



(b) Plotting Waveform, Spectrogram and Mel Spectrogram

In [21]:

```
# Randomly selecting 3 audio files from 3 randomly selected classes out of 35 cl
audio_files = []

classes = np.array(os.listdir(data_path))
classes = np.delete(classes, np.where(classes == '_background_noise_'))

for class_ in random.choices(classes, k=3):
    class_path = os.path.join(data_path, class_)
    for file in np.random.choice(os.listdir(class_path), 3, replace=False):
        if file.endswith('.wav'):
            file_path = os.path.join(class_path, file)

            y, sr = get_amplitude(file_path)
            audio_files.append({
                'file': file,
                'class': class_,
                'y': y,
                'sr': sr
            })

df_audio = pd.DataFrame(audio_files)
df_audio = df_audio.sort_values(by='class')
df_audio.reset_index(drop=True, inplace=True)
df_audio
```

Out[21]:

	file	class	y	sr
0	e04d7130_nohash_0.wav	bird	[6.1035156e-05, 0.00015258789, 0.00012207031, ...	16000
1	234ab0fb_nohash_0.wav	bird	[-0.00015258789, -0.0023498535, -0.0031738281,...	16000
2	ec32860c_nohash_1.wav	bird	[-0.043792725, -0.04953003, -0.052856445, -0.0...	16000
3	ab9b93e4_nohash_1.wav	go	[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, ...	16000
4	617de221_nohash_0.wav	go	[-0.0020446777, -0.003112793, -0.00390625, -0....	16000
5	8fe67225_nohash_1.wav	go	[-0.0002746582, -0.00048828125, -0.00030517578...	16000
6	0ff728b5_nohash_0.wav	happy	[0.0, 3.0517578e-05, -3.0517578e-05, -6.103515...	16000
7	18f8afd5_nohash_0.wav	happy	[-0.00015258789, -0.0011291504, -0.0024719238,...	16000
8	283d7a53_nohash_0.wav	happy	[-0.001159668, 0.0005187988, -0.0004272461, 0....	16000

In [22]:

```
# playing audio files
for i in range(len(df_audio)):
    print(f'Class: {df_audio.loc[i, "class"]}, File: {df_audio.loc[i, "file"]}')
    ipd.display(ipd.Audio(df_audio.loc[i, 'y'], rate=df_audio.loc[i, 'sr']))
```

```
Class: bird, File: e04d7130_nohash_0.wav
```

0:00 / 0:01

```
Class: bird, File: 234ab0fb_nohash_0.wav
```

0:00 / 0:01

```
Class: bird, File: ec32860c_nohash_1.wav
```

0:00 / 0:01

```
Class: go, File: ab9b93e4_nohash_1.wav
```

0:00 / 0:01

```
Class: go, File: 617de221_nohash_0.wav
```

0:00 / 0:01

```
Class: go, File: 8fe67225_nohash_1.wav
```

0:00 / 0:01

Class: happy, File: 0ff728b5_nohash_0.wav

0:00 / 0:01

Class: happy, File: 18f8afd5_nohash_0.wav

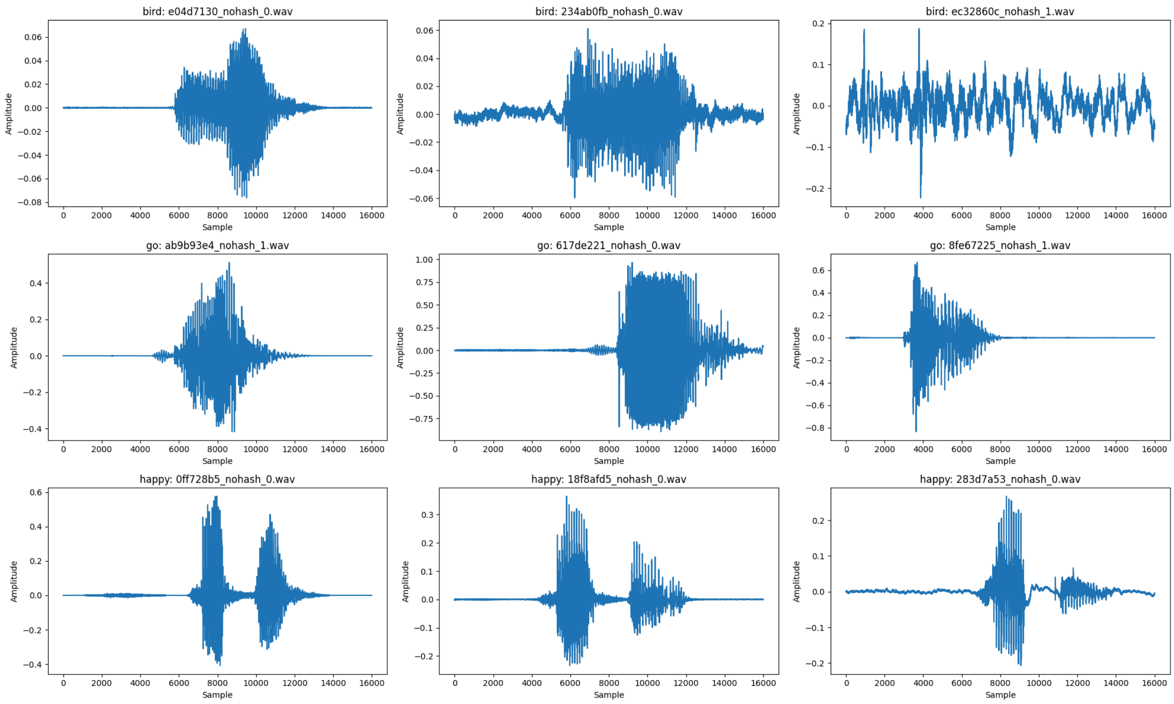
0:00 / 0:01

Class: happy, File: 283d7a53_nohash_0.wav

0:00 / 0:01

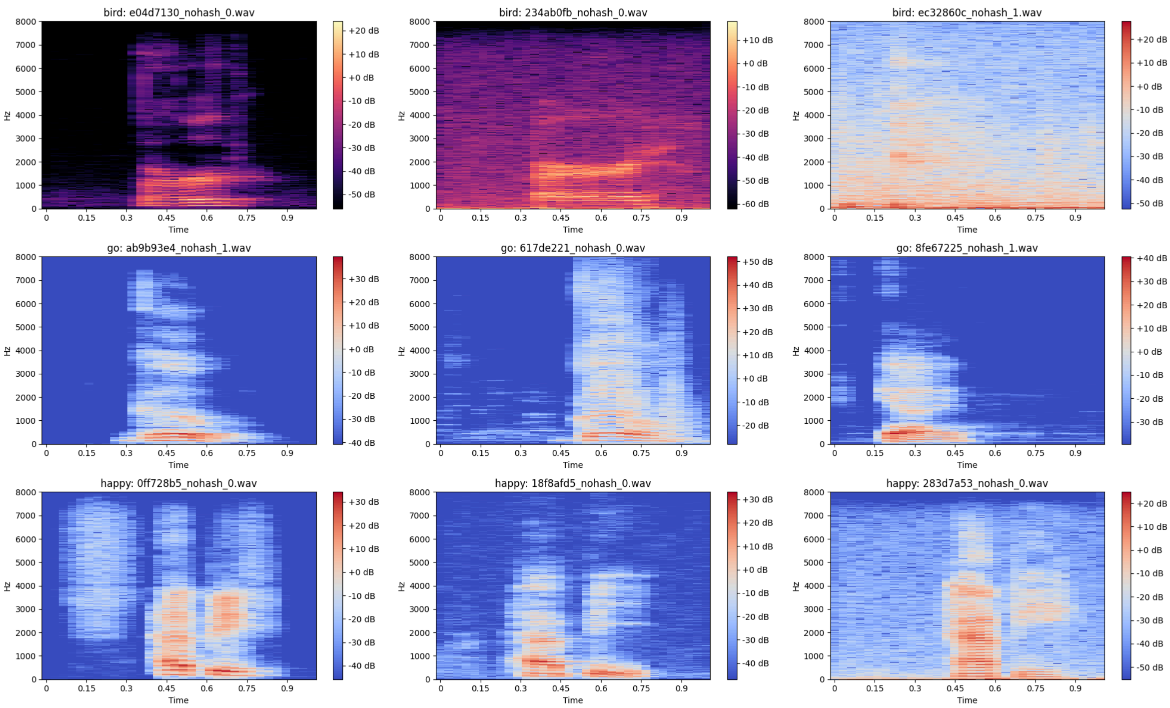
Waveform is used to visualize the amplitude of the data. It is a plot of amplitude vs time.

In [23]:
```python
# waveform
plt.figure(figsize=(20, 12))
for i in range(len(df_audio)):
    plt.subplot(3, 3, i+1)
    plt.plot(df_audio['y'][i])
    plt.title(f'{df_audio["class"][i]}: {df_audio["file"][i]}')
    plt.xlabel('Sample')
    plt.ylabel('Amplitude')

plt.tight_layout()
plt.show()
```



Spectrogram is used to visualize the frequency content of the data. It is a plot of frequency vs time. The color intensity represents the amplitude of the frequency at that time.

In [24]:
```
# spectrogram
plt.figure(figsize=(20, 12))
for i in range(len(df_audio)):
    plt.subplot(3, 3, i+1)
    stft = librosa.stft(df_audio['y'][i])
    spectrogram = librosa.amplitude_to_db(np.abs(stft))

    librosa.display.specshow(spectrogram, sr=df_audio['sr'][i], x_axis='time', y
    plt.colorbar(format='%+2.0f dB')
    plt.title(f'{df_audio["class"][i]}: {df_audio["file"][i]}')


plt.tight_layout()
plt.show()
```



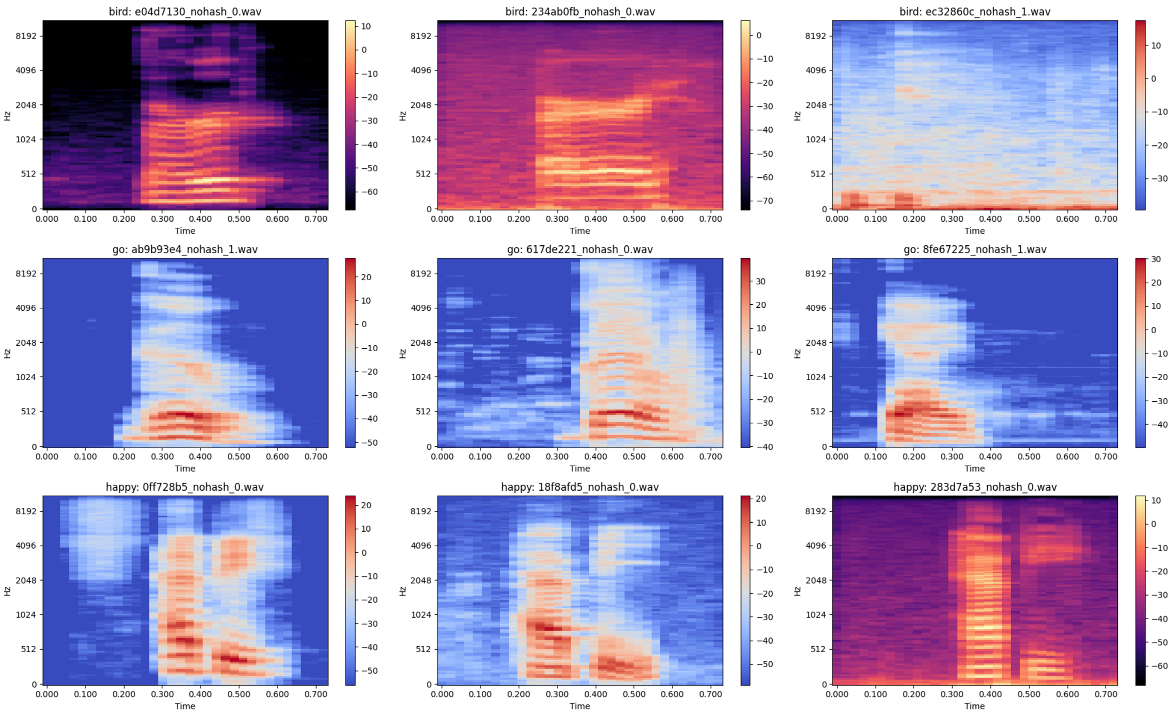
Mel Spectrogram is used to visualize the frequency content of the data. It is a plot of mel frequency vs time. The color intensity represents the amplitude of the mel frequency at that time.

Mel frequency is a scale that is more similar to human perception of sound. It is calculated using the formula:

$$m = 2595 \times \log_{10}(1 + \frac{f}{700})$$

In [25]:
```
# mel spectrogram
plt.figure(figsize=(20, 12))
for i in range(len(df_audio)):
    plt.subplot(3, 3, i+1)
    mel_spectrogram = librosa.feature.melspectrogram(y=df_audio['y'][i], sr=df_a

    librosa.display.specshow(librosa.power_to_db(mel_spectrogram), y_axis='mel',
    plt.colorbar()
    plt.title(f'{df_audio["class"][i]}: {df_audio["file"][i]}')
```

```python
plt.tight_layout()
plt.show()
```



(c) Finding class imbalances and handling them using under sampling

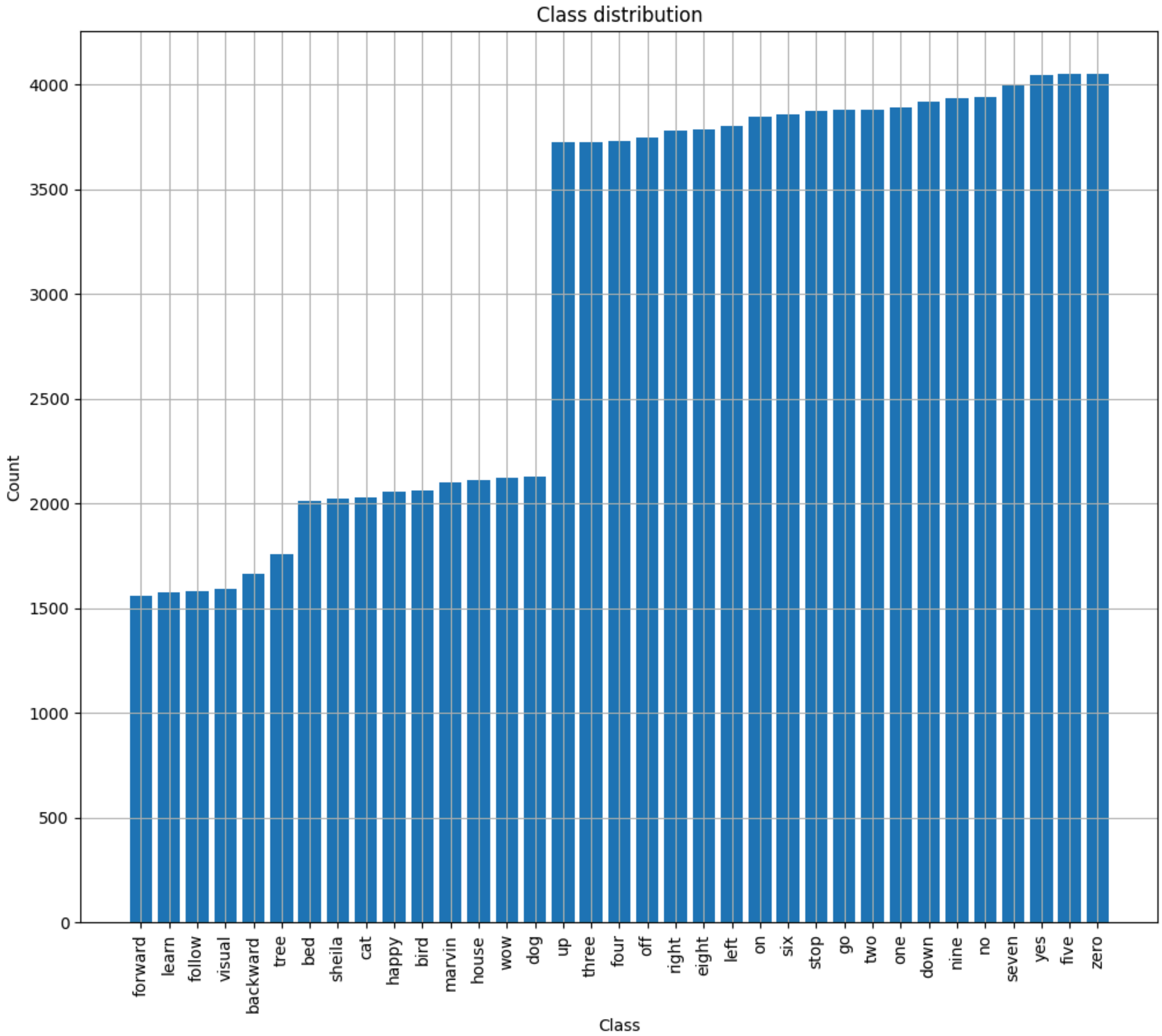
In [27]:
```python
# finding count of each class and storing them in a dataframe
class_count = pd.DataFrame(df_stats['class'].value_counts()).reset_index()
class_count.columns = ['class', 'count']
class_count.sort_values(by='count', inplace=True)
class_count.reset_index(drop=True, inplace=True)
class_count
```

Out[27]:

	class	count
0	forward	1557
1	learn	1575
2	follow	1579
3	visual	1592
4	backward	1664
5	tree	1759
6	bed	2014
7	sheila	2022
8	cat	2031
9	happy	2054
10	bird	2064
11	marvin	2100
12	house	2113
13	wow	2123
14	dog	2128
15	up	3723
16	three	3727
17	four	3728
18	off	3745
19	right	3778
20	eight	3787
21	left	3801
22	on	3845
23	six	3860
24	stop	3872
25	go	3880
26	two	3880
27	one	3890
28	down	3917
29	nine	3934
30	no	3941
31	seven	3998
32	yes	4044

	class	count
33	five	4052
34	zero	4052

In [28]:
```
plt.figure(figsize=(12, 10))
plt.bar(class_count['class'], class_count['count'])
plt.title('Class distribution')
plt.xlabel('Class')
plt.ylabel('Count')
plt.xticks(rotation=90)
plt.grid()
plt.show()
```



The countplot suggests that the data is imbalanced. We can handle this by under sampling the data. We can randomly sample the data from the classes with more samples to match the number of samples in the class with the least number of samples.

Under-sampling is a technique used to balance the class distribution of a dataset by reducing the number of samples in the over-represented class.

In [31]:
```
# undersampling
min_count = class_count['count'].min()
```

```
for class_ in class_count['class']:
    class_path = os.path.join(data_path, class_)
    for file in np.random.choice(os.listdir(class_path), len(os.listdir(class_pa
        if file.endswith('.wav'):
            file_path = os.path.join(class_path, file)
            os.remove(file_path)
```

In [40]:

```
stats_new = []
# creating a new dataframe after undersampling
for class_ in os.listdir(data_path):
    if class_ == '_background_noise_':
        continue
    class_path = os.path.join(data_path, class_)
    for file in os.listdir(class_path):
        if file.endswith('.wav'):
            file_path = os.path.join(class_path, file)
            y, sr = get_amplitude(file_path)

            stats = {
                'file': file,
                'class': class_,
                'y': y,
                'sr': sr,
            }

            stats_new.append(stats)
```

In [34]:

```
df_stats = pd.DataFrame(stats_new)
df_stats.sort_values(by='class', inplace=True)
df_stats.reset_index(drop=True, inplace=True)
df_stats
```

Out[34]:

	file	class	y	sr
0	0165e0e8_nohash_0.wav	backward	[-0.06576538, -0.07092285, -0.07531738, -0.079...	16000
1	b29f8b23_nohash_1.wav	backward	[-0.00024414062, -0.0070495605, -0.01687622, -...	16000
2	b29f8b23_nohash_0.wav	backward	[-0.00088500977, -0.0018005371, -0.0016479492,...	16000
3	b0f5b16d_nohash_4.wav	backward	[0.0, 0.0, -3.0517578e-05, -6.1035156e-05, -6....	16000
4	b0f5b16d_nohash_3.wav	backward	[-3.0517578e-05, -3.0517578e-05, 6.1035156e-05...	16000
...	...	...	...	...
54490	51f7a034_nohash_3.wav	zero	[0.00021362305, -6.1035156e-05, -0.00021362305...	16000
54491	51f7a034_nohash_2.wav	zero	[3.0517578e-05, 6.1035156e-05, 0.00012207031, ...	16000
54492	5184ed3e_nohash_0.wav	zero	[0.0012512207, 0.0038757324, 0.0058898926, 0.0...	16000
54493	563aa4e6_nohash_2.wav	zero	[0.00024414062, 0.00024414062, 0.00021362305, ...	16000
54494	fffcabd1_nohash_0.wav	zero	[-0.0009765625, -0.0008544922, -0.0011901855, ...	16000

54495 rows × 4 columns

In [35]:

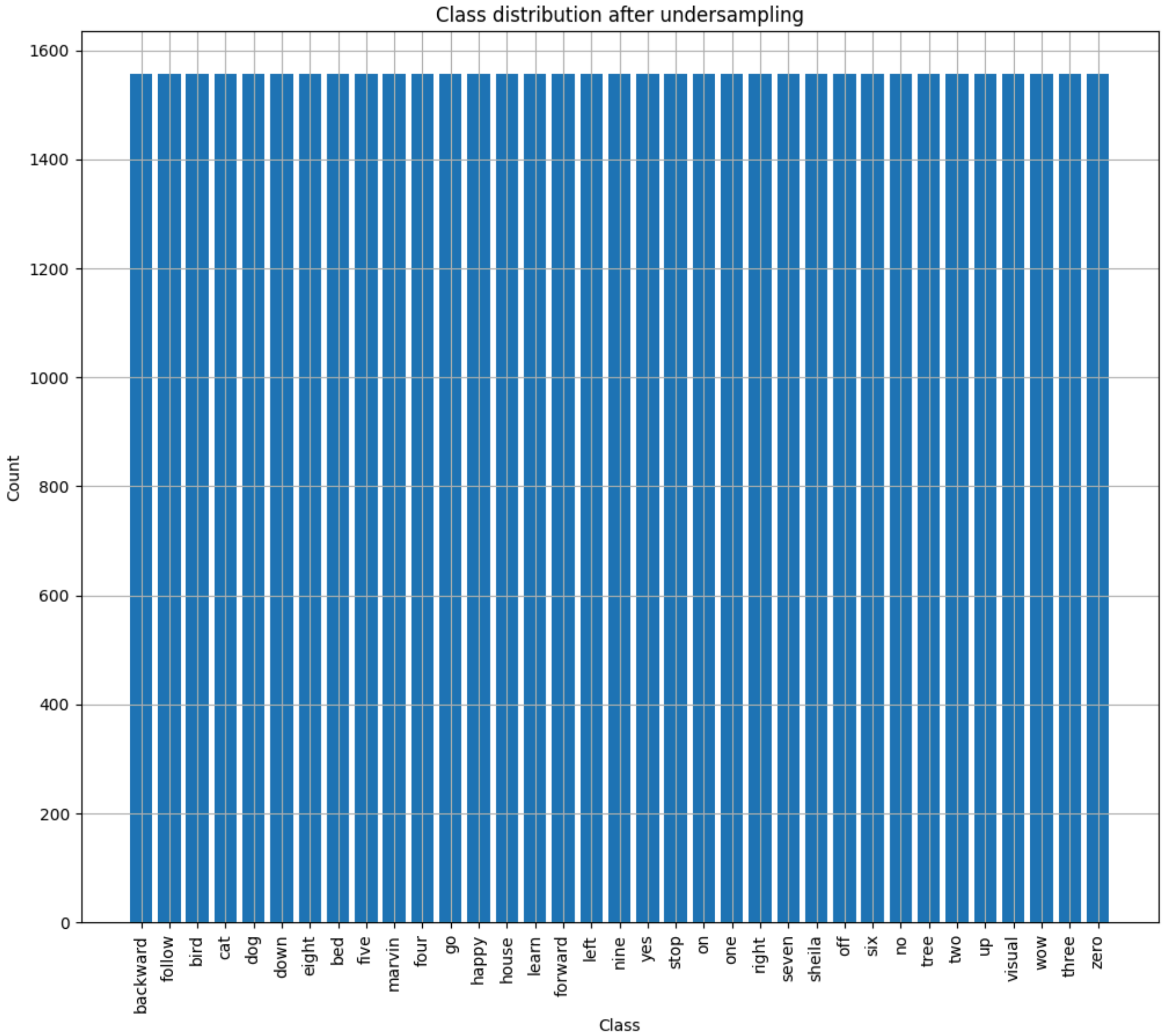
```
# finding count of each class and storing
class_count = pd.DataFrame(df_stats['class'].value_counts()).reset_index()
class_count.columns = ['class', 'count']
class_count.sort_values(by='count', inplace=True)
class_count.reset_index(drop=True, inplace=True)
class_count
```

Out[35]:

	class	count
0	backward	1557
1	follow	1557
2	bird	1557
3	cat	1557
4	dog	1557
5	down	1557
6	eight	1557
7	bed	1557
8	five	1557
9	marvin	1557
10	four	1557
11	go	1557
12	happy	1557
13	house	1557
14	learn	1557
15	forward	1557
16	left	1557
17	nine	1557
18	yes	1557
19	stop	1557
20	on	1557
21	one	1557
22	right	1557
23	seven	1557
24	sheila	1557
25	off	1557
26	six	1557
27	no	1557
28	tree	1557
29	two	1557
30	up	1557
31	visual	1557
32	wow	1557

	class	count
33	three	1557
34	zero	1557

In [36]:
```
plt.figure(figsize=(12, 10))
plt.bar(class_count['class'], class_count['count'])
plt.title('Class distribution after undersampling')
plt.xlabel('Class')
plt.ylabel('Count')
plt.xticks(rotation=90)
plt.grid()
plt.show()
```



Each class has 1557 samples after under sampling.

(d) Cleaning the data by removing silence and low noise from the audio files

In [81]:
```
# # removing files starting with clean
# for class_ in os.listdir(data_path):
#     if class_ == '_background_noise_':
#         continue
#     class_path = os.path.join(data_path, class_)
#     for file in os.listdir(class_path):
```

```
#         if file.startswith('clean'):
#             os.remove(os.path.join(class_path, file))
```

In [37]:
```
def detect_silent_segments(audio, sr, threshold=0.05, min_silence_len=0.2):

    min_silence_samples = int(min_silence_len * sr)

    silent_samples = np.where(np.abs(audio) < threshold)[0]

    silence_segments = []
    start = None
    for i in range(1, len(silent_samples)):
        if silent_samples[i] != silent_samples[i-1] + 1:
            if start is not None and i - start >= min_silence_samples:
                silence_segments.append((silent_samples[start] / sr, silent_samp
            start = None
        else:
            if start is None:
                start = i

    if start is not None and len(silent_samples) - start >= min_silence_samples:
        silence_segments.append((silent_samples[start] / sr, silent_samples[-1]

    return silence_segments
```

In [38]:
```
def remove_silent_segments(audio, sr, silence_segments):

    cleaned_audio = []
    prev_end = 0
    for start, end in silence_segments:
        cleaned_audio.append(audio[int(prev_end * sr):int(start * sr)])
        prev_end = end
    cleaned_audio.append(audio[int(prev_end * sr):])

    return np.concatenate(cleaned_audio)
```

In [41]:
```
# testing on a single audio file
file_path = 'data/yes/0a2b400e_nohash_0.wav'
y, sr = get_amplitude(file_path)

silence_segments = detect_silent_segments(y, sr)
cleaned_audio = remove_silent_segments(y, sr, silence_segments)

ipd.display(ipd.Audio(y, rate=sr))
```

0:00 / 0:01

Writing cleaned audio files into the dirrectory.

In [39]:
```
for class_ in os.listdir(data_path):
    if class_ == '_background_noise_':
        continue
    class_path = os.path.join(data_path, class_)
    for file in os.listdir(class_path):
        if file.endswith('.wav'):
            file_path = os.path.join(class_path, file)
```

```
            y, sr = get_amplitude(file_path)

            silent_segments = detect_silent_segments(y, sr)
            clean_audio = remove_silent_segments(y, sr, silent_segments)

            if clean_audio.shape[0] < sr:
                clean_audio = np.pad(clean_audio, (0, sr - clean_audio.shape[0])
            elif clean_audio.shape[0] > sr:
                clean_audio = clean_audio[:sr]

            clean_file_path = os.path.join(class_path, f'clean_{file}')
            soundfile.write(clean_file_path, clean_audio, sr)
```

In [6]:
```
classes = np.array(os.listdir(data_path))
```

In [42]:
```
cleaned_audio = []

for class_ in random.choices(classes, k=3):
    class_path = os.path.join(data_path, class_)
    files = os.listdir(class_path)
    files = [file for file in files if file.startswith('clean_')]
    for file in np.random.choice(files, 3, replace=False):
        file_path = os.path.join(class_path, file)

        y, sr = get_amplitude(file_path)
        duration = librosa.get_duration(y=y, sr=sr)
        cleaned_audio.append({
            'file': file,
            'class': class_,
            'y': y,
            'sr': sr,
            'duration' : duration
        })

df_cleaned_audio = pd.DataFrame(cleaned_audio)
df_cleaned_audio = df_cleaned_audio.sort_values(by='class')
df_cleaned_audio.reset_index(drop=True, inplace=True)
df_cleaned_audio
```

Out[42]:

	file	class	y	sr	duration
0	clean_3d86b69a_nohash_3.wav	no	[0.036895752, 0.04159546, 0.04626465, 0.050750...	16000	1.0
1	clean_0c2d2ffa_nohash_0.wav	no	[0.0005493164, 0.039215088, 0.052612305, 0.063...	16000	1.0
2	clean_81332c92_nohash_3.wav	no	[0.00018310547, -0.040618896, -0.05014038, -0....	16000	1.0
3	clean_5b09db89_nohash_0.wav	no	[-0.0013427734, -0.0034484863, -0.005279541, -...	16000	1.0
4	clean_e32ff49d_nohash_2.wav	no	[-0.00018310547, -0.0010681152, -0.001373291, ...	16000	1.0
5	clean_bfd26d6b_nohash_1.wav	no	[3.0517578e-05, -0.00018310547, -3.0517578e-05...	16000	1.0
6	clean_24a3e589_nohash_1.wav	zero	[-9.1552734e-05, -9.1552734e-05, -6.1035156e-0...	16000	1.0
7	clean_b97c9f77_nohash_3.wav	zero	[-0.00036621094, -0.04638672, -0.05029297, -0....	16000	1.0
8	clean_71d0ded4_nohash_3.wav	zero	[-0.00012207031, 0.048309326, 0.058013916, 0.0...	16000	1.0

In [43]:

```
for i in range(len(df_cleaned_audio)):
    print(f'Class: {df_cleaned_audio.loc[i, "class"]}, File: {df_cleaned_audio.l
    ipd.display(ipd.Audio(df_cleaned_audio.loc[i, 'y'], rate=df_cleaned_audio.lc
```

```
Class: no, File: clean_3d86b69a_nohash_3.wav
```

```
Class: no, File: clean_0c2d2ffa_nohash_0.wav
```

```
Class: no, File: clean_81332c92_nohash_3.wav
```

```
Class: no, File: clean_5b09db89_nohash_0.wav
```

```
Class: no, File: clean_e32ff49d_nohash_2.wav
```

0:00 / 0:01

```
Class: no, File: clean_bfd26d6b_nohash_1.wav
```

0:00 / 0:01

```
Class: zero, File: clean_24a3e589_nohash_1.wav
```

0:00 / 0:01

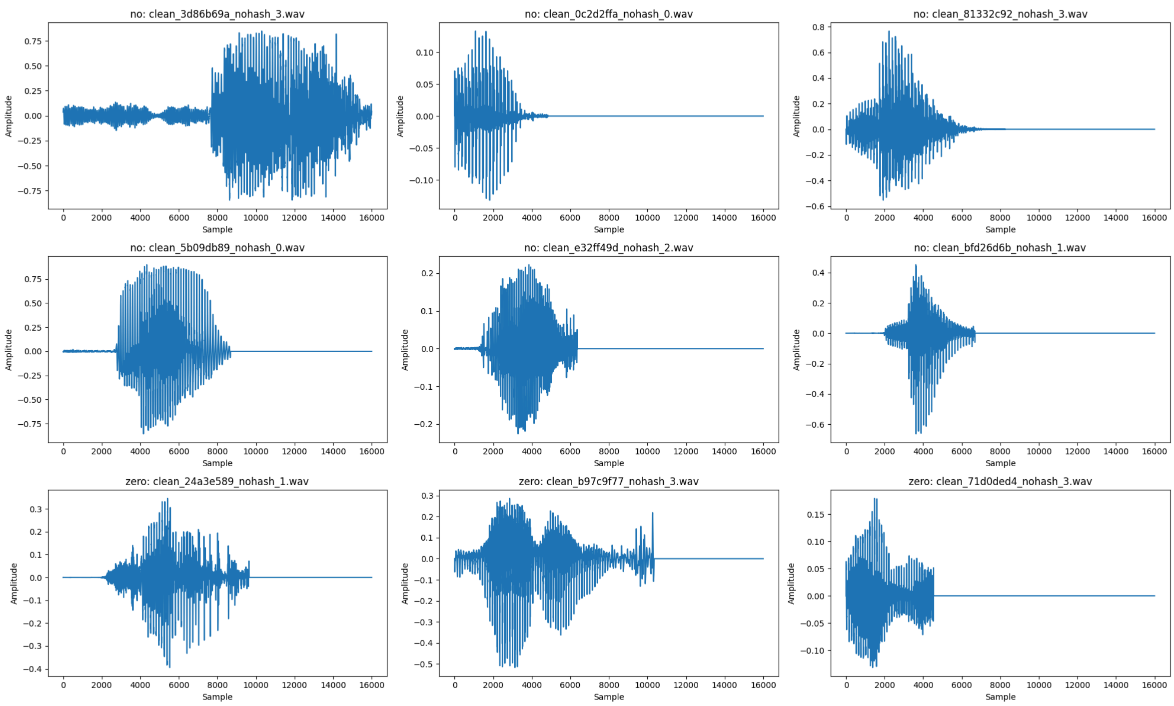
```
Class: zero, File: clean_b97c9f77_nohash_3.wav
```

0:00 / 0:01

```
Class: zero, File: clean_71d0ded4_nohash_3.wav
```

0:00 / 0:01

In [44]:
```
plt.figure(figsize=(20, 12))
for i in range(len(df_cleaned_audio)):
    plt.subplot(3, 3, i+1)
    plt.plot(df_cleaned_audio['y'][i])
    plt.title(f'{df_cleaned_audio["class"][i]}: {df_cleaned_audio["file"][i]}')
    plt.xlabel('Sample')
    plt.ylabel('Amplitude')

plt.tight_layout()
plt.show()
```



From the above plots we can see that silence has been removed from between the words.

In [45]:
```
# removing low noise from the cleaned audio
def calc_snr(audio, noise_threshold=0.02):
    signal_power = np.mean(audio ** 2)
    noise_power = np.mean(audio[np.abs(audio) < noise_threshold] ** 2)

    if noise_power == 0:
        return float('inf')

    snr = 10 * np.log10(signal_power / noise_power)

    return snr
```

In [94]:
```
# testing on a single audio file
file_path = 'data/yes/clean_0a2b400e_nohash_0.wav'
y, sr = get_amplitude(file_path)
snr = calc_snr(y)
print(f'SNR: {snr}')
if snr < 10:
    print("file would be removed")
else:
    print("file would be kept")
```

```
SNR: 25.70021390914917
file would be kept
```

Removing files which have signal to noise ratio less than 10.

In [46]:
```
clean_audio_df = []

for class_ in os.listdir(data_path):
    if class_ == '_background_noise_':
        continue
    class_path = os.path.join(data_path, class_)
    counter = 0
    for file in os.listdir(class_path):
        if file.startswith('clean_') and file.endswith('.wav'):
            file_path = os.path.join(class_path, file)
            y, sr = get_amplitude(file_path)
            snr = calc_snr(y)
            # print(f'Class: {class_}, File: {file}, SNR: {snr}')
            if snr < 10:
                os.remove(file_path)
            else:
                counter += 1
                clean_audio_df.append({
                    'file': file,
                    'class': class_,
                    'y': y,
                })
    print(f'Class: {class_}, Files kept: {counter}')

df_clean_audio = pd.DataFrame(clean_audio_df)
df_clean_audio.sort_values(by='class', inplace=True)
df_clean_audio.reset_index(drop=True, inplace=True)
df_clean_audio
# if clean_audio_df:
#     clean_audio_df = pd.DataFrame(clean_audio_df)

#     print(clean_audio_df.head())
```

```
#     if 'class' in clean_audio_df.columns:
#         clean_audio_df.sort_values(by='class', inplace=True)
#         clean_audio_df.reset_index(drop=True, inplace=True)
#     else:
#         print("The 'class' column is missing from the DataFrame.")
# else:
#     print("No clean audio files found.")

# clean_audio_df
```

```
Class: backward, Files kept: 1524
Class: bed, Files kept: 1487
Class: bird, Files kept: 1468
Class: cat, Files kept: 1475
C:\Users\Ritika\AppData\Local\Packages\PythonSoftwareFoundation.Python.3.11_qbz5n
2kfra8p0\LocalCache\local-packages\Python311\site-packages\numpy\core\fromnumeri
c.py:3504: RuntimeWarning: Mean of empty slice.
  return _methods._mean(a, axis=axis, dtype=dtype,
C:\Users\Ritika\AppData\Local\Packages\PythonSoftwareFoundation.Python.3.11_qbz5n
2kfra8p0\LocalCache\local-packages\Python311\site-packages\numpy\core\_methods.p
y:129: RuntimeWarning: invalid value encountered in divide
  ret = ret.dtype.type(ret / rcount)
Class: dog, Files kept: 1451
Class: down, Files kept: 1475
Class: eight, Files kept: 1514
Class: five, Files kept: 1510
Class: follow, Files kept: 1509
Class: forward, Files kept: 1510
Class: four, Files kept: 1486
Class: go, Files kept: 1506
Class: happy, Files kept: 1473
Class: house, Files kept: 1461
Class: learn, Files kept: 1522
Class: left, Files kept: 1511
Class: marvin, Files kept: 1397
Class: nine, Files kept: 1453
Class: no, Files kept: 1490
Class: off, Files kept: 1516
Class: on, Files kept: 1494
Class: one, Files kept: 1489
Class: right, Files kept: 1489
Class: seven, Files kept: 1490
Class: sheila, Files kept: 1354
Class: six, Files kept: 1464
Class: stop, Files kept: 1515
Class: three, Files kept: 1468
Class: tree, Files kept: 1397
Class: two, Files kept: 1494
Class: up, Files kept: 1536
Class: visual, Files kept: 1488
Class: wow, Files kept: 1429
Class: yes, Files kept: 1475
Class: zero, Files kept: 1447
```

Out[46]:

	file	class	y
0	clean_0165e0e8_nohash_0.wav	backward	[-0.06576538, -0.07092285, -0.07531738, -0.079...
1	clean_b2ae3928_nohash_0.wav	backward	[6.1035156e-05, 0.027130127, 0.050567627, 0.03...
2	clean_b29f8b23_nohash_3.wav	backward	[0.0024719238, 0.0012512207, -0.0010375977, 0....
3	clean_b29f8b23_nohash_2.wav	backward	[-0.0002746582, -0.00030517578, -6.1035156e-05...
4	clean_b29f8b23_nohash_1.wav	backward	[-0.00024414062, -0.0070495605, -0.01687622, -...
...	...	...	...
51762	clean_520e8c0e_nohash_0.wav	zero	[0.0, 0.028961182, 0.050689697, 0.040008545, 0...
51763	clean_51f7a034_nohash_3.wav	zero	[0.00021362305, -6.1035156e-05, -0.00021362305...
51764	clean_51f7a034_nohash_2.wav	zero	[3.0517578e-05, 0.04373169, 0.09451294, 0.1026...
51765	clean_5170b77f_nohash_4.wav	zero	[0.0007324219, 0.0007324219, 0.0009460449, 0.0...
51766	clean_fffcabd1_nohash_0.wav	zero	[-0.0009765625, -0.0008544922, -0.0011901855, ...

51767 rows × 3 columns

In [47]:

```
# # checking to see if duplicate files are present in a class
# for class_ in os.listdir(data_path):
#     if class_ == '_background_noise_':
#         continue
#     class_path = os.path.join(data_path, class_)
#     files = os.listdir(class_path)
#     files = [file for file in files if file.startswith('clean_')]
#     if len(files) != len(set(files)):
#         print(f'Duplicates found in class: {class_}')
```

In [51]:

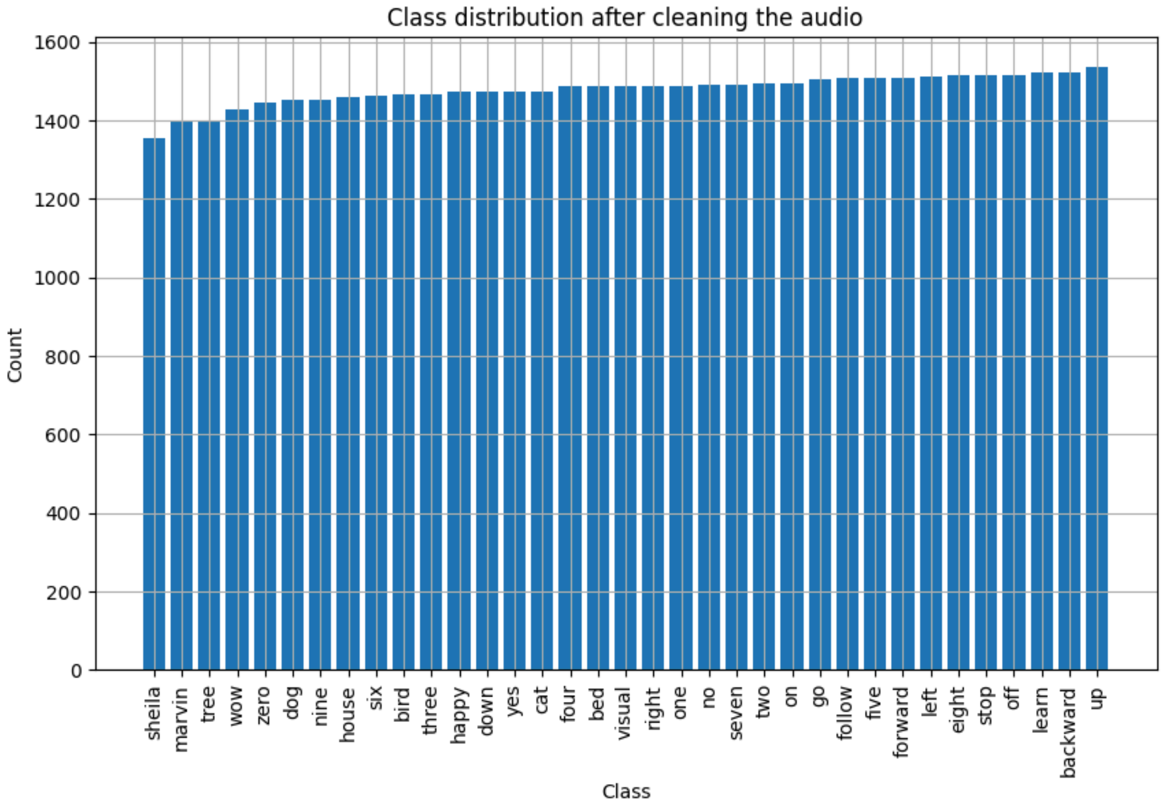
```
# counting total number of files
total_files = len(df_clean_audio)
print(f'Total number of files: {total_files}')
```

```
Total number of files: 51767
```

In [52]:

```
counts = pd.DataFrame(df_clean_audio['class'].value_counts()).reset_index()
counts.columns = ['class', 'count']
counts.sort_values(by='count', inplace=True)
counts.reset_index(drop=True, inplace=True)

plt.figure(figsize=(10, 6))
plt.bar(counts['class'], counts['count'])
plt.title('Class distribution after cleaning the audio')
plt.xlabel('Class')
```

```
plt.ylabel('Count')
plt.xticks(rotation=90)
plt.grid()
plt.show()
```



We now have a balanced dataset where each class has clean audio files.

(2) Feature Extraction

rms - root mean square of the audio signal
rms is a measure of the power of the audio signal. It is calculated as the square root of the mean of the square of the audio signal.

In [53]:
```
def rms(y=None, S=None, frame_length=2048, hop_length=512, center=True, pad_mode

    # If `y` (audio samples) is provided
    if y is not None:
        if center:
            # Padding the signal to center the frames
            padding = [(0, 0) for _ in range(y.ndim)]  # Padding setup for all a
            padding[-1] = (int(frame_length // 2), int(frame_length // 2))  # La
            y = np.pad(y, padding, mode=pad_mode)

        # Frame the audio signal
        x = frame(y, frame_length=frame_length, hop_length=hop_length)

        # Calculate the power (mean squared value)
        power = np.mean(abs2(x, dtype=dtype), axis=-2, keepdims=True)

    # If `S` (spectrogram) is provided
    elif S is not None:
        # Validate frame length for spectrogram input
```

```
        if S.shape[-2] != frame_length // 2 + 1:
            raise ValueError(
                f"S.shape[-2] is {S.shape[-2]}, but frame_length should be {S.sh
                f"{S.shape[-2] * 2 - 1}, found {frame_length}"
            )

        # Compute power from spectrogram magnitude
        x = abs2(S, dtype=dtype)

        # Adjust for DC (0 Hz) and Nyquist (sr/2) components
        x[..., 0, :] *= 0.5  # Adjust DC component
        if frame_length % 2 == 0:
            x[..., -1, :] *= 0.5  # Adjust Nyquist component for even frame leng

        # Calculate the power by summing across frequency bins
        power = 2 * np.sum(x, axis=-2, keepdims=True) / frame_length**2

    else:
        raise ValueError("Either `y` or `S` must be provided as input.")

    # Compute the RMS value (square root of power)
    rms_result = np.sqrt(power)
    return rms_result
```

zcr - zero crossing rate of the audio signal
zcr is a measure of the number of times the audio signal crosses the zero axis. It is calculated as the number of times the audio signal changes sign divided by the total number of samples.

In [54]:
```
def zero_crossings(y, threshold=1e-10, ref_magnitude=None, pad=True, zero_pos=Tr

    # Apply ref_magnitude scaling to threshold if needed
    if callable(ref_magnitude):
        threshold = threshold * ref_magnitude(np.abs(y))
    elif ref_magnitude is not None:
        threshold = threshold * ref_magnitude

    # Swap the specified axis to the last axis for easier processing
    y_swapped = np.swapaxes(y, axis, -1)

    # Initialize a boolean array for zero-crossings
    z = np.empty_like(y_swapped, dtype=bool)

    # Compute the sign difference between consecutive elements to detect zero-cr
    z[..., :-1] = np.sign(y_swapped[..., :-1]) != np.sign(y_swapped[..., 1:])

    # Handle the case of zero_pos, where 0 is treated as positive
    if zero_pos:
        z[..., :-1] |= (y_swapped[..., :-1] == 0)

    # Pad the first element with `True` if `pad=True`
    z[..., 0] = pad

    # Swap the axes back to the original order
    return np.swapaxes(z, -1, axis)

def zero_crossing_rate(y: np.ndarray, frame_length: int = 2048, hop_length: int
    if center:
```

```
        padding = [(0, 0) for _ in range(y.ndim)]
        padding[-1] = (int(frame_length // 2), int(frame_length // 2))
        y = np.pad(y, padding, mode="edge")

    # Frame the audio signal
    y_framed = frame(y, frame_length=frame_length, hop_length=hop_length)

    # Compute zero crossings
    crossings = zero_crossings(y_framed, threshold=threshold, ref_magnitude=ref_

    # Calculate zero-crossing rate
    zcr = np.mean(crossings, axis=axis, keepdims=True)

    return zcr
```

formants - formants of the audio signal
Formants are the resonant frequencies of the vocal tract. They are calculated using linear predictive coding (LPC).
LPC is a method used to represent the spectral envelope of the audio signal. It is calculated by finding the coefficients of the filter that best fits the audio signal.

In [55]:
```
def lpc(signal, order):
    # Autocorrelation method for LPC
    autocorr = np.correlate(signal, signal, mode='full')
    autocorr = autocorr[len(autocorr)//2:]

    R = autocorr[:order + 1]
    a = np.zeros(order)
    E = R[0]

    for i in range(order):
        # Reflection coefficient
        if E == 0:
            break
        k = - (R[i+1] + np.dot(a[:i], R[i:0:-1])) / E
        a[i] = k

        # Update LPC coefficients
        if i > 0:
            a[:i] += k * a[i-1::-1]

        # Update error
        E *= (1 - k**2)

    return np.hstack([[1], -a])

def get_formants(audio, sr):
    # Step 1: Apply pre-emphasis to the audio signal to enhance higher frequenci
    pre_emphasis = 0.97
    emphasized_audio = np.append(audio[0], audio[1:] - pre_emphasis * audio[:-1]

    # Step 2: Frame the signal (breaking into short segments) and apply LPC
    frame_size = int(0.025 * sr)  # 25ms window size
    frame_stride = int(0.01 * sr) # 10ms stride
    frames = []

    # Sliding window to break signal into frames
    for i in range(0, len(emphasized_audio) - frame_size, frame_stride):
```

```
        frames.append(emphasized_audio[i:i + frame_size])

    # Step 3: LPC analysis
    formants = []
    for frame in frames:
        # Apply Hamming window to each frame
        windowed_frame = frame * np.hamming(len(frame))

        # Perform LPC analysis (using order 2 + sr // 1000, a common heuristic f
        lpc_coeffs = lpc(windowed_frame, 2 + sr // 1000)

        # Step 4: Find roots of the LPC polynomial and keep only the roots that
        roots = np.roots(lpc_coeffs)
        roots = [r for r in roots if np.imag(r) >= 0]

        # Convert roots into formant frequencies
        formant_freqs = np.angle(roots) * (sr / (2 * np.pi))

        # Keep the first three formants (F1, F2, F3)
        formant_freqs = sorted(formant_freqs)
        if len(formant_freqs) >= 3:
            formants.append(formant_freqs[:3])

    # Average formants over all frames
    formants = np.mean(formants, axis=0)

    return formants
```

The above codes have been taken from the source codes of the respective libraries: https://github.com/librosa/librosa/blob/main/librosa/feature/spectral.py

We are going to extract the followinf features: MFCC, RMS, ZCR, Spectral Centroid, Spectral Bandwidth, Spectral Contrast, Spectral Rolloff, Chroma, Mel Spectrogram, Spectral Flatness, Tempo, Pitch, Mel Spectogram, Chroma_cqt and Formants.

In [59]:
```
feature_names = []
class_labels = []
audio_files = []

for class_ in os.listdir(data_path):
    if class_ == '_background_noise_':
        continue
    class_path = os.path.join(data_path, class_)
    for file in os.listdir(class_path):
        if file.endswith('.wav') and file.startswith('clean_'):
            file_path = os.path.join(class_path, file)
            audio, sr = get_amplitude(file_path)

            # MFCC
            mfcc = librosa.feature.mfcc(y=audio, sr=sr, n_mfcc=13)
            mfcc_mean = np.mean(mfcc, axis=1)

            mfcc_delta = librosa.feature.delta(mfcc)
            mfcc_delta_mean = np.mean(mfcc_delta, axis=1)

            mfcc_delta2 = librosa.feature.delta(mfcc, order=2)
            mfcc_delta2_mean = np.mean(mfcc_delta2, axis=1)
```

```
        # Chroma
        chroma = librosa.feature.chroma_stft(y=audio, sr=sr)
        chroma_mean = np.mean(chroma, axis=1)

        # Spectral
        spectral_centroid = librosa.feature.spectral_centroid(y=audio, sr=sr
        spectral_centroid_mean = np.mean(spectral_centroid)

        spectral_bandwidth = librosa.feature.spectral_bandwidth(y=audio, sr=
        spectral_bandwidth_mean = np.mean(spectral_bandwidth)

        spectral_contrast = librosa.feature.spectral_contrast(y=audio, sr=sr
        spectral_contrast_mean = np.mean(spectral_contrast, axis=1)

        spectral_flatness = librosa.feature.spectral_flatness(y=audio)
        spectral_flatness_mean = np.mean(spectral_flatness)

        spectral_roloff = librosa.feature.spectral_rolloff(y=audio, sr=sr)
        spectral_roloff_mean = np.mean(spectral_roloff)

        # RMS
        rms_value = rms(y=audio)
        rms_mean = np.mean(rms_value)

        # Zero crossing rate
        zcr = zero_crossing_rate(y=audio)
        zcr_mean = np.mean(zcr)

        # Tempo
        # onset_env = librosa.onset.onset_strength(y=audio, sr=sr)
        tempo, _ = librosa.beat.beat_track(y=audio, sr=sr)

        # Pitch
        pitches, magnitudes = librosa.piptrack(y=audio, sr=sr)
        pitch_mean = np.mean(pitches)

        # Mel spectrogram
        mel_spectrogram = librosa.feature.melspectrogram(y=audio, sr=sr)
        mel_spectrogram_mean = np.mean(mel_spectrogram)

        # Chroma cqt
        chroma_cqt = librosa.feature.chroma_cqt(y=audio, sr=sr)
        chroma_cqt_mean = np.mean(chroma_cqt, axis=1)

        # Formant
        f1, f2, f3 = get_formants(audio, sr)

        features = {'mfcc_1' : mfcc_mean[0], 'mfcc_2' : mfcc_mean[1], 'mfcc_
                    'mfcc_5' : mfcc_mean[4], 'mfcc_6' : mfcc_mean[5], 'mfcc_
                    'mfcc_9' : mfcc_mean[8], 'mfcc_10' : mfcc_mean[9], 'mfcc
                    'mfcc_13' : mfcc_mean[12],

                    'mfcc_delta_1' : mfcc_delta_mean[0], 'mfcc_delta_2' : mf
                    'mfcc_delta_4' : mfcc_delta_mean[3], 'mfcc_delta_5' : mf
                    'mfcc_delta_7' : mfcc_delta_mean[6], 'mfcc_delta_8' : mf
                    'mfcc_delta_10' : mfcc_delta_mean[9], 'mfcc_delta_11' :
                    'mfcc_delta_13' : mfcc_delta_mean[12],

                    'mfcc_delta2_1' : mfcc_delta2_mean[0], 'mfcc_delta2_2' :
                    'mfcc_delta2_4' : mfcc_delta2_mean[3], 'mfcc_delta2_5' :
```

```
                            'mfcc_delta2_7' : mfcc_delta2_mean[6], 'mfcc_delta2_8' :
                            'mfcc_delta2_10' : mfcc_delta2_mean[9], 'mfcc_delta2_11'
                            'mfcc_delta2_13' : mfcc_delta2_mean[12],

                            'chroma_1' : chroma_mean[0], 'chroma_2' : chroma_mean[1]
                            'chroma_5' : chroma_mean[4], 'chroma_6' : chroma_mean[5]
                            'chroma_9' : chroma_mean[8], 'chroma_10' : chroma_mean[9

                            'spectral_centroid' : spectral_centroid_mean, 'spectral_
                            'spectral_contrast_1' : spectral_contrast_mean[0], 'spec
                            'spectral_contrast_4' : spectral_contrast_mean[3], 'spec

                            'spectral_flatness' : spectral_flatness_mean, 'rms' : rm
                            'pitch' : pitch_mean, 'mel_spectrogram' : mel_spectrogra

                            'chroma_cqt_1' : chroma_cqt_mean[0], 'chroma_cqt_2' : ch
                            'chroma_cqt_5' : chroma_cqt_mean[4], 'chroma_cqt_6' : ch
                            'chroma_cqt_9' : chroma_cqt_mean[8], 'chroma_cqt_10' : c

                            'f1' : f1, 'f2' : f2, 'f3' : f3
                        }

            class_labels.append(class_)
            audio_files.append(file)
            feature_names.append(features)

features_df = pd.DataFrame(feature_names)
features_df['class'] = class_labels
features_df['file'] = audio_files
features_df
```

Out[59]:

	mfcc_1	mfcc_2	mfcc_3	mfcc_4	mfcc_5	mfcc_6	mfcc_
0	-273.752625	139.112671	-2.639945	-13.992020	7.489814	27.705564	-2.08070
1	-401.402832	88.338226	-22.921865	-6.252601	-8.850283	-1.071088	-15.27122
2	-462.968506	83.527039	-27.385208	-4.816205	-15.408574	0.764183	-14.08304
3	-407.912292	87.522057	-26.431669	-3.974614	-5.922104	-4.061956	-15.88099
4	-407.722290	79.652122	-25.731075	-8.634889	-12.981051	2.209030	-19.20148
...	...	...	...	...	...	...	
51762	-408.390320	50.964191	8.647757	13.604553	-6.363612	10.950428	-8.54846
51763	-350.134827	83.939819	8.200066	4.566678	-15.972693	-5.031384	-18.60998
51764	-488.792175	43.622475	14.833714	12.864100	5.101717	10.201158	-6.87686
51765	-463.622467	49.546898	15.482666	20.839153	10.603121	7.938496	-2.16220
51766	-487.396301	64.183701	-1.536087	3.786770	3.913802	0.645614	-21.32639

51767 rows × 83 columns

In [60]:

```
features_df.sort_values(by='class', inplace=True)
features_df.reset_index(drop=True, inplace=True)

tempos = []
```

```
for tempo in features_df['tempo']:
    if type(tempo) == list:
        tempos.append(tempo[0])
    elif type(tempo) == np.ndarray:
        tempos.append(tempo[0])
    elif type(tempo) == float or type(tempo) == int or type(tempo) == np.float64
        tempos.append(tempo)

features_df['tempo'] = tempos
features_df
```

Out[60]:

	mfcc_1	mfcc_2	mfcc_3	mfcc_4	mfcc_5	mfcc_6	mfc
0	-273.752625	139.112671	-2.639945	-13.992020	7.489814	27.705564	-2.0807
1	-631.483093	24.472626	0.978857	3.669819	-1.342214	-0.073142	-5.7453
2	-186.506653	115.250053	4.416769	7.393332	-12.270612	-10.438718	1.3015
3	-325.645630	55.496346	22.701229	7.521428	-8.602731	-10.047596	-8.8504
4	-154.654648	103.791832	16.406778	-7.059024	-9.648861	-6.824230	-5.8827
...	...	...	...	...	...	...	
51762	-402.895782	95.353981	1.202288	-27.545485	-11.962097	-18.070713	-9.9964
51763	-387.056885	61.908249	-22.958073	26.020023	-20.180145	-11.643095	-8.3636
51764	-450.818207	59.472824	-34.393425	15.677197	-10.576280	-11.931031	-2.9781
51765	-395.548157	49.749512	11.180022	9.734412	-0.602622	-2.773630	-17.8835
51766	-487.396301	64.183701	-1.536087	3.786770	3.913802	0.645614	-21.3263

51767 rows × 83 columns

In [61]:

```
# bring the class column to the front
cols = features_df.columns.tolist()
cols = cols[-2:] + cols[:-2]
features_df = features_df[cols]
features_df
```

Out[61]:

	class	file	mfcc_1	mfcc_2	mfcc_3	
0	backward	clean_0165e0e8_nohash_0.wav	-273.752625	139.112671	-2.639945	-13.
1	backward	clean_b2ae3928_nohash_0.wav	-631.483093	24.472626	0.978857	3.
2	backward	clean_b29f8b23_nohash_3.wav	-186.506653	115.250053	4.416769	7.
3	backward	clean_b29f8b23_nohash_2.wav	-325.645630	55.496346	22.701229	7.
4	backward	clean_b29f8b23_nohash_1.wav	-154.654648	103.791832	16.406778	-7.
...	...	...	...	...	...	
51762	zero	clean_520e8c0e_nohash_0.wav	-402.895782	95.353981	1.202288	-27.
51763	zero	clean_51f7a034_nohash_3.wav	-387.056885	61.908249	-22.958073	26.
51764	zero	clean_51f7a034_nohash_2.wav	-450.818207	59.472824	-34.393425	15.
51765	zero	clean_5170b77f_nohash_4.wav	-395.548157	49.749512	11.180022	9.
51766	zero	clean_fffcabd1_nohash_0.wav	-487.396301	64.183701	-1.536087	3.

51767 rows × 83 columns

In [62]:

```
features_df = features_df.sample(frac = 1, random_state=42).reset_index(drop=Tru
features_df.to_csv('audio_features.csv', index=False)
```

In [64]:

```
# remove all clean files
for class_ in os.listdir(data_path):
    if class_ == '_background_noise_':
        continue
    class_path = os.path.join(data_path, class_)
    for file in os.listdir(class_path):
        if file.startswith('clean_'):
            os.remove(os.path.join(class_path, file))
```

In [ ]: